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ADDENDUM TO FINAL REPORT

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ADDENDUM TO FINAL REPORT

TO

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

ON

(NASA Contract NAS5-1607)
Awarded 11/21/61

Voltage
regulation]

To ESB/MBD

ESB Report No. E-32-63

June 14, 1963

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ref's

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ESB-E-32-63, Addendum)

final
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DISCHARGE TESTS, STORAH 67

CAPACITY RETENTION AND VOLTAGE REGULATION OF STORAGE CELLS

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I. INTRODUCTION

The Final Report on Contract NASS-1607 (ESB Report No. E-6-63, dated 21 March 1963), stated (page 23) that two addenda would be submitted to report additional data, which was not available at that time. This single addendum report contains all the data referred to and completes the requirements of the contract.

II. STANDARD DISCHARGE TESTS

Incomplete discharge curves of cells at the 1000-hour rate (Model 217 cell S/N's 25 and 32) and the 2000-hour rate (Model 216 Cell S/N's 8, 15, and 25 - Model 217 cell S/N's 4, 6, 11, 18, and 22 - Model 218 cell S/N's 1, 18, and 20) were presented in Figures 15, 12, 16, and 20 of the Final Report. These curves have been completed and are included in this addendum as Figures 1, 2, 3, and 4. Table 1 summarizes the performance of these cells and may be compared to Table XII (Page 46) of the Final Report. Such a comparison will reveal that, at 10 and 25°C, similar capacities and energy densities were displayed by cells discharged at the 1000-hour and the 2000-hour rates. At the 1000-hour rate, cells discharged at 50°C showed some performance degradation as compared to those discharged at 10 and 25°C, due to the effect of high temperature "storage" (for almost 2 months) concurrent with their discharge. This process was in effect for periods in excess of three months with cells discharged at the 2000-hour rate at 50°C and resulted in lower capacities than those achieved at the 1000-hour rate.

Nevertheless, the three cells discharged at the 2000-hour rate at 50°C (216 S/N-15, 217 S/N-22, and 218 S/N-1) provided capacities in excess of their nominals, and only the Model 216 cell had energy densities below the design objective of 65-75 watt-hours per pound and 5-6 watt-hours per cubic inch.

Model 217 cell S/N's 6 and 18 were discharged upside down at the 2000-hour rate. The identical performance of these units to that of S/N's 11 and 4, which were discharged upright under the same conditions, indicates the position insensitivity of the cell design.

III. VACUUM DISCHARGE TESTS

Four Model 217 cells were discharged at 50°C under a soft vacuum of approximately 8 mm of mercury in the apparatus illustrated in Figure 5. One cell was discharged at each of the 20, 100, 1000, and 2000-hour rates. Performance comparisons at the three lower rates are made with cells discharged at the same rates and temperature but at ambient pressure in Table II and Figure 6. Comparable capacity and voltage characteristics were achieved under both pressure conditions.

Cell S/N 8 shorted after 1600 hours of vacuum discharge at the 2000-hour rate. Post-mortem of the cell revealed an improper epoxy resin pot in the area of the separator envelope tops to have provided the probable shorting path. No evidence of shorting through the separator system was observed. There is no indication that

the failure was due to the discharge being carried out under vacuum. This same shorting mechanism brought about the failure of a Model 216 cell which was on test at the Goddard Space Flight Center. To date (approximately 6 months after manufacture) only these two cells, of the 91 qualification lot units, have shorted.

IV. CHARGED STORAGE CAPACITY RETENTION

Capacity loss rates of Model 218 cells, on charged storage at 52°C for periods of 0.5 and 1 month, were presented in the Final Report (page 23). The experiment was concluded with the determination of this parameter for 2 Model 218 and 2 Model 216 cells which had been stored at 52°C for 2 months. Table III summarizes the results of the entire experiment, while Figures 7 and 8 demonstrate the voltage regulation after storage. The 6.1 per cent difference in loss rate between the Model 218 and 216 cells probably is due to the difference in separator systems and to the thinner Model 216 plates.

Experimental sealed cells, similar in design to the qualification lot units, were subjected to various storage periods up to 9 months at -18, +10, 32, and 52°C. Capacity retention data obtained during this program is summarized in Table IV. Figure 9 is a plot of % capacity loss per month versus storage temperature based on the experimental cell data with points from the above Model 216 and Model 218 storage experiment included for comparison.

Per cent capacity retained is plotted against storage time, at the three test temperatures, in Figure 10. It was observed that the

greatest loss rate occurred early in storage. This is in keeping with data presented by Dirkse (1), which indicates that an initial reaction of silver with the first layer of cellophane is required to make the cellophane an efficient multilayer separator system. Additionally, an initial reaction between the positive plates and starch in the Synpor separator may have been contributory. Accordingly, the data of Figure 10 is plotted as an initial loss to 3/4 month (the first test storage period), then a steady loss rate based on the average of observed values for periods beyond 3/4 month.

V. VOLTAGE REGULATION

The Final Report presented data showing that, under normal conditions, initial discharge voltages of the Model 216, 217, and 218 cells were above the design objective maximum of 1.65 volts per cell. At that time it was pointed out that initial voltage peaks were eliminated by storage at elevated temperature but that this method involved a small sacrifice in capacity. Since that time, preliminary results have been obtained from an internally sponsored program in which several methods of lowering initial discharge voltage are being investigated. While it is too early to present definite conclusions, one method, which would involve no changes in present cell designs, is showing promise as a technique whereby cells would deliver full capacity entirely at lower plateau voltages.

VI. SUMMARY AND CONCLUSIONS

A. Work Completed Since Final Report. -

1. Completion of standard discharge tests permits updating the capacity and energy density summary table of the Final Report (Pages 26 and 27) as follows:

Contract Objectives	Mean and (Range) of Test Results*		
	Model 216	Model 217	Model 218
Capacity-30, 60, and 120 Amp-Hrs.	38 (33/42)	81 (73/89)	168 (152/179)
Energy Density-65 to 75 Watt-Hrs. per lb.	72 (63/79)	84 (75/94)	89 (78/94)
Energy Density-5 to 6 Watt-Hrs. per in ³	5.5 (4.9/6.1)	7.5 (6.7/8.3)	8.3 (7.2/8.7)

(*) Based on discharges at the 20, 100, 1000, and 2000-hour rates at 10, 25, and 50°C.

2. Discharges at the 1000 and 2000-hour rates at 50°C resulted in some capacity decrease due to the effect of high temperature "storage" concurrent with the discharge. Capacity design objectives were still exceeded by considerable margins under these conditions.

3. Position insensitivity of the design was indicated by the identical performance at the 2000-hour rate of cells discharged upside down and upright.

4. Model 217 cells were found to be subject to no performance degradation due to being discharged under a soft vacuum of approximately 8 mm of mercury.

5. Charged storage capacity retention studies, based largely on experimental cells of similar design but with high temperature

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confirmation from Model 216 and 218 cells, indicate that Model 216, 217, and 218 storage capacity losses will be lower than design objectives of 1, 4, 10, and 20 per cent per month at 0, 22, 38, and 54°C, respectively.

B. General Conformance to Contract Objectives. - Test results show that, with the sole exception of having initial discharge voltages above desirable levels (an exception which may well be eliminated in the near future as a result of studies being conducted by ESB/MBD), the Model 216, 217, and 218 cells will meet or exceed all contract objectives.

VII. REFERENCE

- (1) Dirkse, T.P., Separators for Alkaline Batteries - Paper delivered at 17th Annual Power Sources Conference, Atlantic City, N.J., May 23, 1963.

TABLE I

DISCHARGE PERFORMANCE OF QUALIFICATION LOT CELLS

Model, S/N	Input Capacity (Amp-Hrs)	Nominal Discharge Rate (Ohrs)	Constant Resistance (Ohms)	Discharge Temperature (°C)	Output Capacity (Amp-Hrs)	% Of Input	Efficiency (Amp-Hrs per Gm of Silver)		Energy Density (Watt-Hrs Per Lb.)	Density (Watt-Hrs Per in. ³)
							Gm of Silver	(Amp-Hrs per Lb.)		
216	25	42.2	2000	105	10	39.4	93	0.342	74.9	5.7
	8	45.9	2000	105	41.4	90	0.360	77.4	6.0	6.0
	15	42.2	2000	105	33.4	79	0.290	63.0	4.9	4.9
217	25	92.1	1000	25	10	88.4	96	0.386	93.6	8.3
	32	81.3	1000	25	Room (25)	77.1	94	0.337	81.6	7.3
	4	83.2	2000	52	10	79.0	95	0.345	84.4	7.4
218	18*	83.2	2000	52	10	79.3	95	0.346	84.7	7.4
	11	86.0	2000	52	Room (25)	81.3	95	0.355	87.1	7.6
	6*	85.5	2000	52	Room (25)	81.2	95	0.354	87.0	7.6
218	22	85.8	2000	52	50	72.7	85	0.317	77.9	6.8
	20	189.7	2000	23	10	175.6	93	0.341	93.8	8.7
	18	182.9	2000	23	Room (25)	174.1	95	0.339	92.5	8.7
	1	187.8	2000	23	50	160.6	86	0.312	85.8	8.0

(*) Discharged upside down.

TABLE II

COMPARISON OF DISCHARGE PERFORMANCE - MODEL 217 CELLS DISCHARGED
 UNDER SOFT VACUUM AND AT AMBIENT PRESSURE AT 50°C

S/N	Input Capacity (Amp-Hrs.)	Vacuum	Nominal Discharge Rate (Hrs.)	Output Capacity (Amp-Hrs.)	% Of Input	Efficiency (Amp-Hrs per gm. of Silver)	Energy Density	
							(Watt-Hrs. Per lb.)	(Watt-Hrs. Per in.)
26	93.9	c. a. 8 mm. of Hg	20	87.6	93	0.382	89.3	8.0
31	82.4	None	20	77.5	94	0.338	78.7	7.1
7	93.9	c. a. 8mm. of Hg.	100	87.1	93	0.380	91.0	8.1
14	86.6	None	100	78.4	90	0.342	81.0	7.3
13	88.3	c. a. 8mm. of Hg	1000	80.9	92	0.353	86.6	7.6
21	83.2	None	1000	75.9	91	0.331	84.4	7.4

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TABLE III
 CHARGED STORAGE CAPACITY RETENTION OF MODEL 218 & MODEL 216 CELLS

Cell Type	Model 218*												Model 216**											
	Cell S/N	19	28	12	4	16	8	11	3	24	20	Cell S/N	19	28	12	4	16	8	11	3	24	20		
Storage Period at 52°C (Months)	0	1/2	1/2	1/2	1	2	2	2	0	2	2	Storage Period at 52°C (Months)	0	1/2	1	2	2	2	2	0	2	2		
Input Capacity (Amp-Hrs)	194.8	177.1	177.1	177.1	177.9	176.0	177.9	177.9	172.3	172.3	172.3	Output Capacity (Amp-Hrs)	178.9	152.2	154.4	140.9	141.2	124.9	129.2	39.9	25.8	26.1	26.1	
Output/Input X 100 (%)	91.84	85.94	87.18	79.20	80.23	70.21	73.36	94.33	60.23	60.91	60.91	Mean Output/Input X 100 (%)	91.84	86.56	79.72	71.79	94.33	60.57	60.57	94.33	60.57	60.57		
Mean Output/Input X Median Input of All Cells In Model Qualification Lot (Amp-Hrs)	164.7	155.3	143.0	128.9	128.9	11.4	13.2	10.9	11.4	11.4	11.4	Capacity Loss Over Storage Period (Amp-Hrs)	---	9.4	21.7	35.8	-	-	-	14.9	-	14.9		
Capacity Loss Over Storage Period (%)	---	5.7	13.2	21.8	21.8	11.4	13.2	10.9	11.4	11.4	11.4	Capacity Loss Per Month	---	---	---	---	---	---	---	35.8	21.8	35.8		
Mean Capacity Loss per Month at 52°C (%)	---	---	---	---	---	---	---	---	---	---	---	Design Objective Capacity Loss Per Month (Max. %)	---	---	---	---	---	---	---	---	---	---		

(*) LL polypropylene plus 5L 0.001" cellulose.
 (**) LL ESB-Reeves Syntac plus 5L 0.001" cellulose.

TABLE IV

CAPACITY RETENTION OF LOW RATE SEALED TEST CELLS
 DURING CHARGED STORAGE AT TEMPERATURES OF -18, +10, 32 AND 52°C
 POSITIVE PLATE THICKNESS = 0.064 INCH

Storage Period (Days)	Mean Calculated Capacity Loss (%) ^a			Mean Calculated Capacity Loss Per Month Of Charged Storage (%)	
	Capacity Retained At -18 °C For Same Storage Period To Represent 0% Loss				
	Storage Temperature (°C)	10	32		
23	3.0 ^b	4.2	15.9	3.9	
38	--	3.7	6.8	--	
58	--	2.0	31.9	--	
97	2.7	9.3	--	0.8	
180	3.9	--	--	0.7	
270	5.9	--	--	0.7	
				Mean % Capacity Loss Per Month	
				1.5	
				3.1	
				14.2	

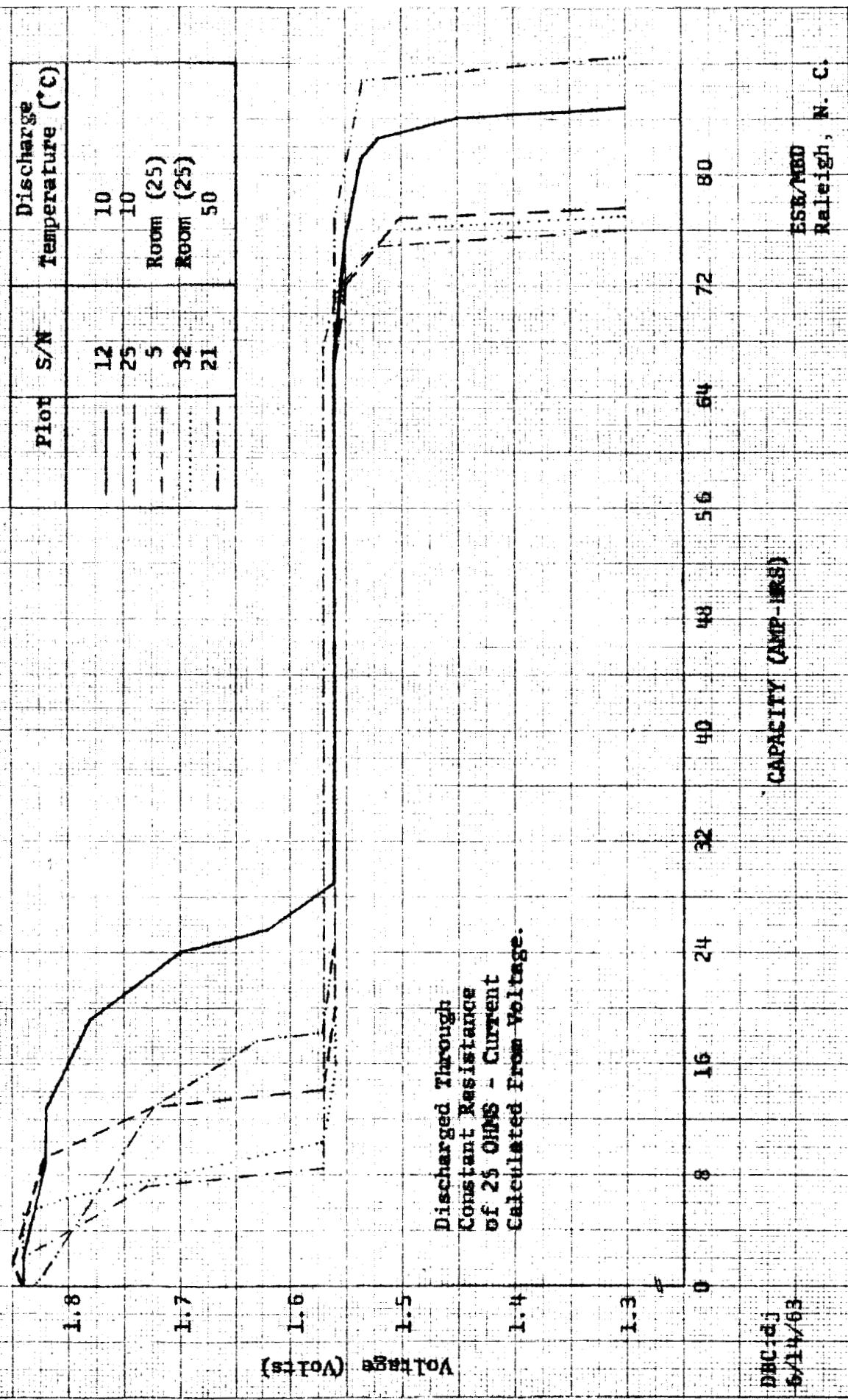
(*) A factor to compensate
for differences in charge
input was included in these
calculations - for this
reason, there are minor
differences between the
figures shown and those pre-
sented in the "Final Report"
Table VIII, Page 42.

^a Each data point represents the mean of two cells.

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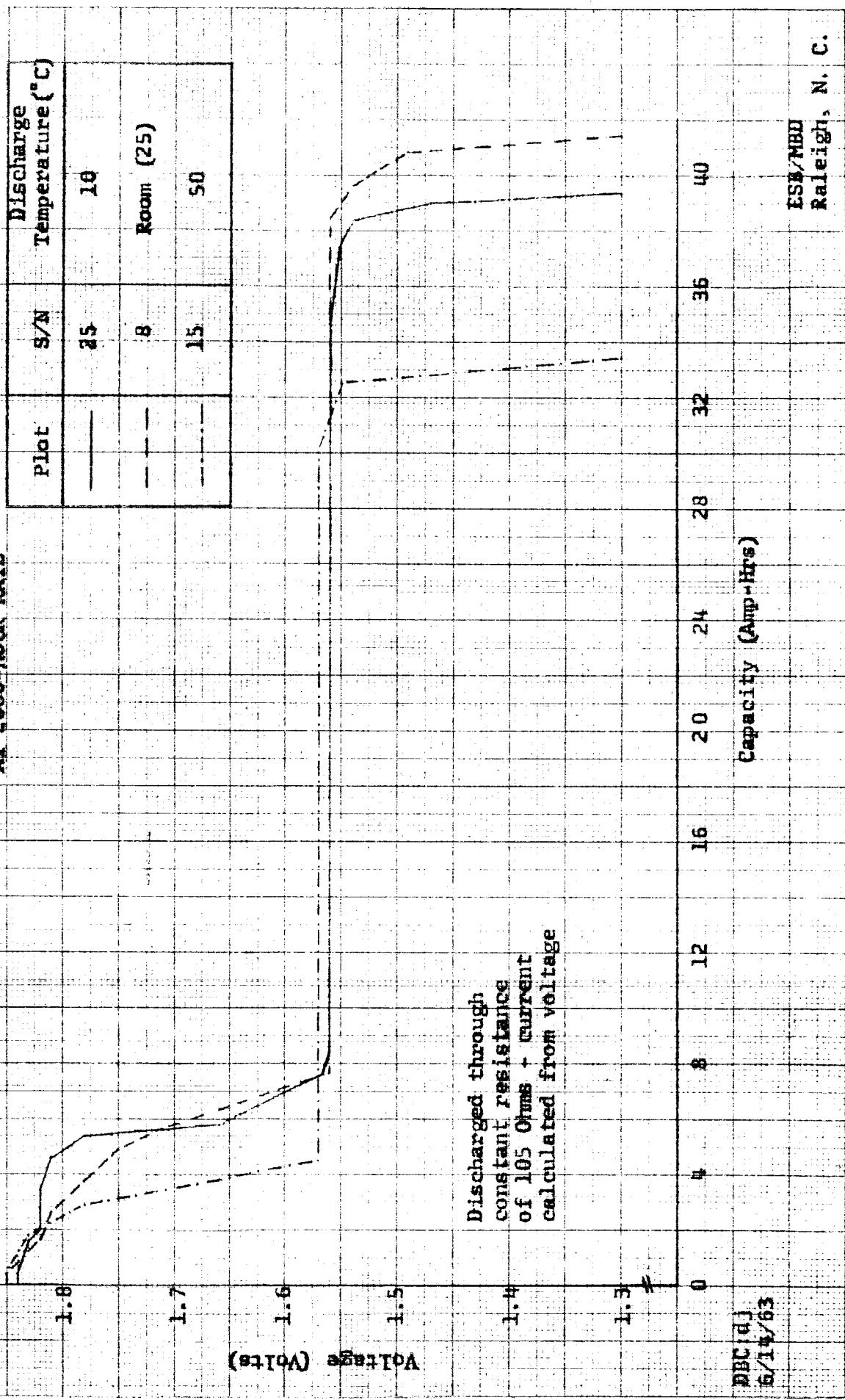
FIGURE 1
MODEL 217 DISCHARGE CURVES
AT 1000-HOUR RATE



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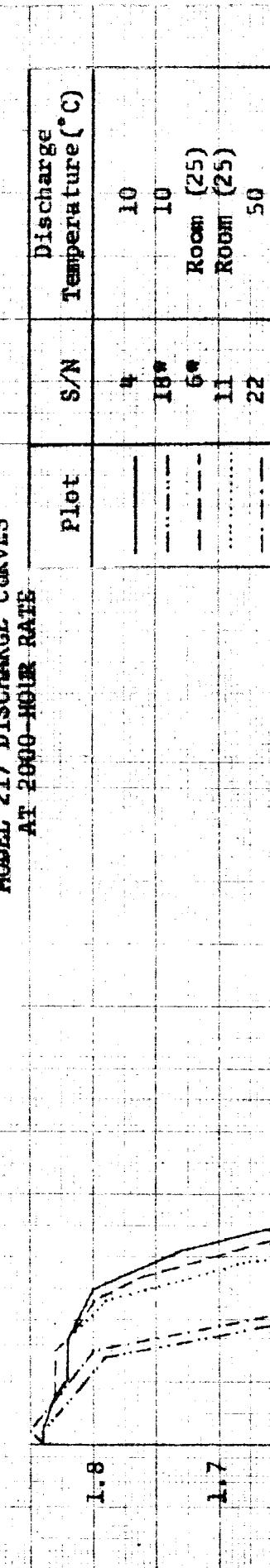
FIGURE 2

MODEL 216 DISCHARGE CURVES
AT 2000-HOUR RATE



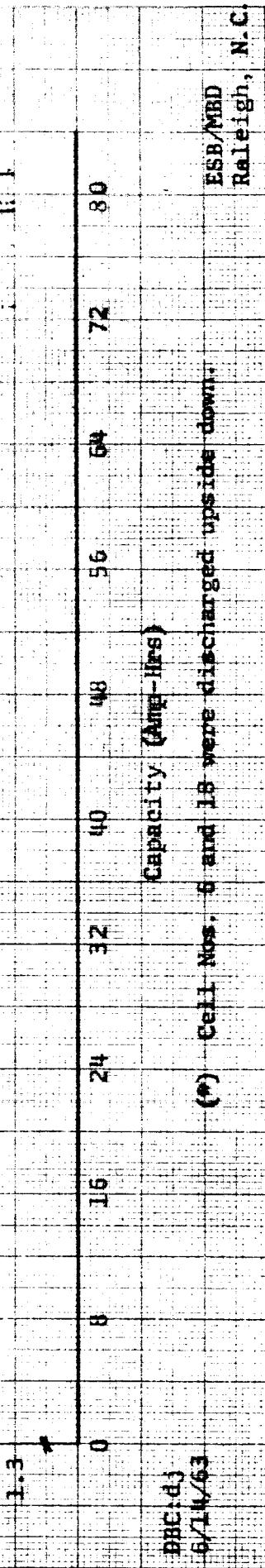
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FIGURE 3
MODEL 217 DISCHARGE CURVES
AT 2000-HOUR RATE



1.5 Discharged through constant
resistance of 52 ohms -
current calculated from
voltage.

1.4



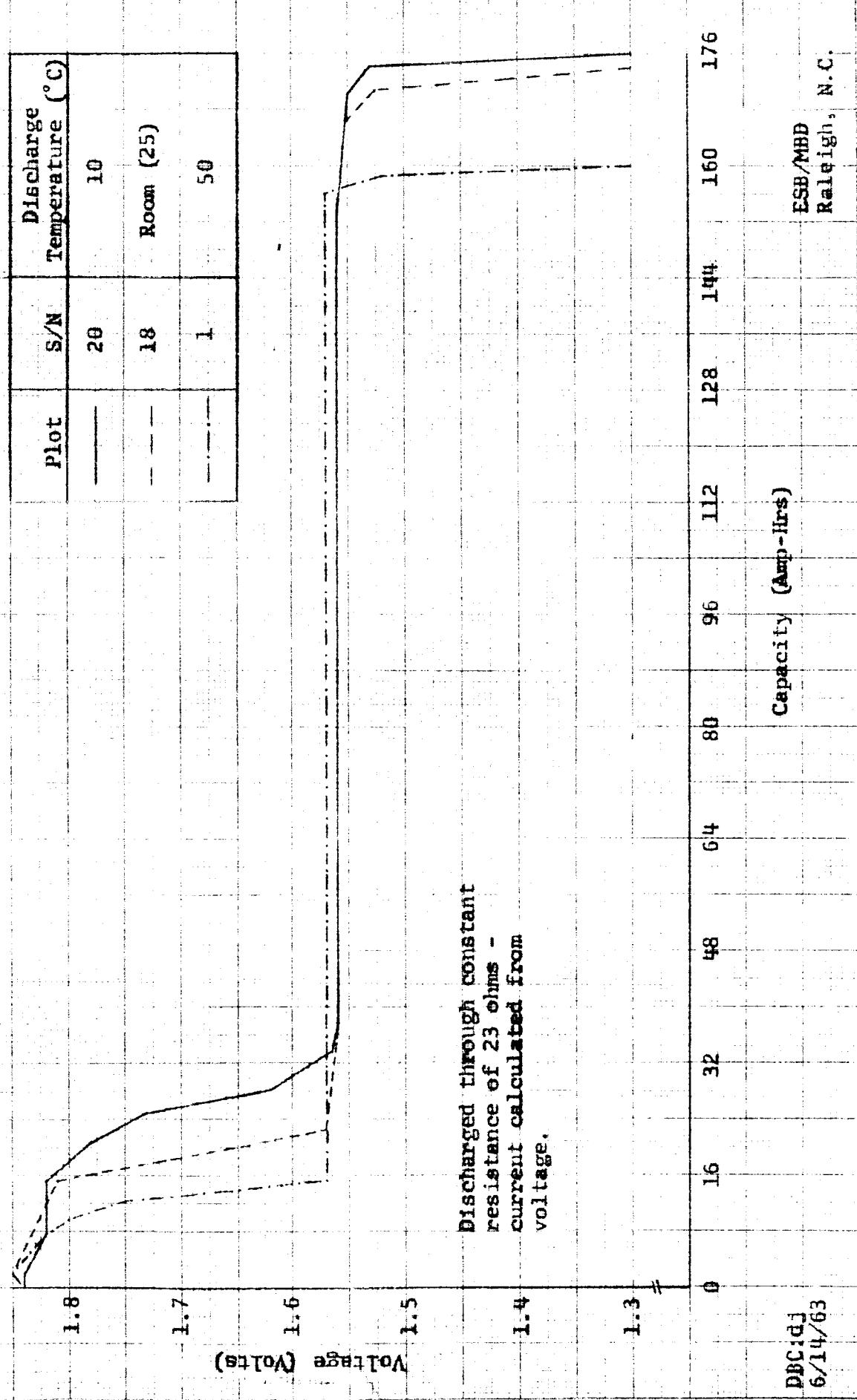
(*) Cell Nos. 6 and 18 were discharged upside down.

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FIGURE 4
MODEL 2118 DISCHARGE CURVES
AT 2000-HOUR RATE

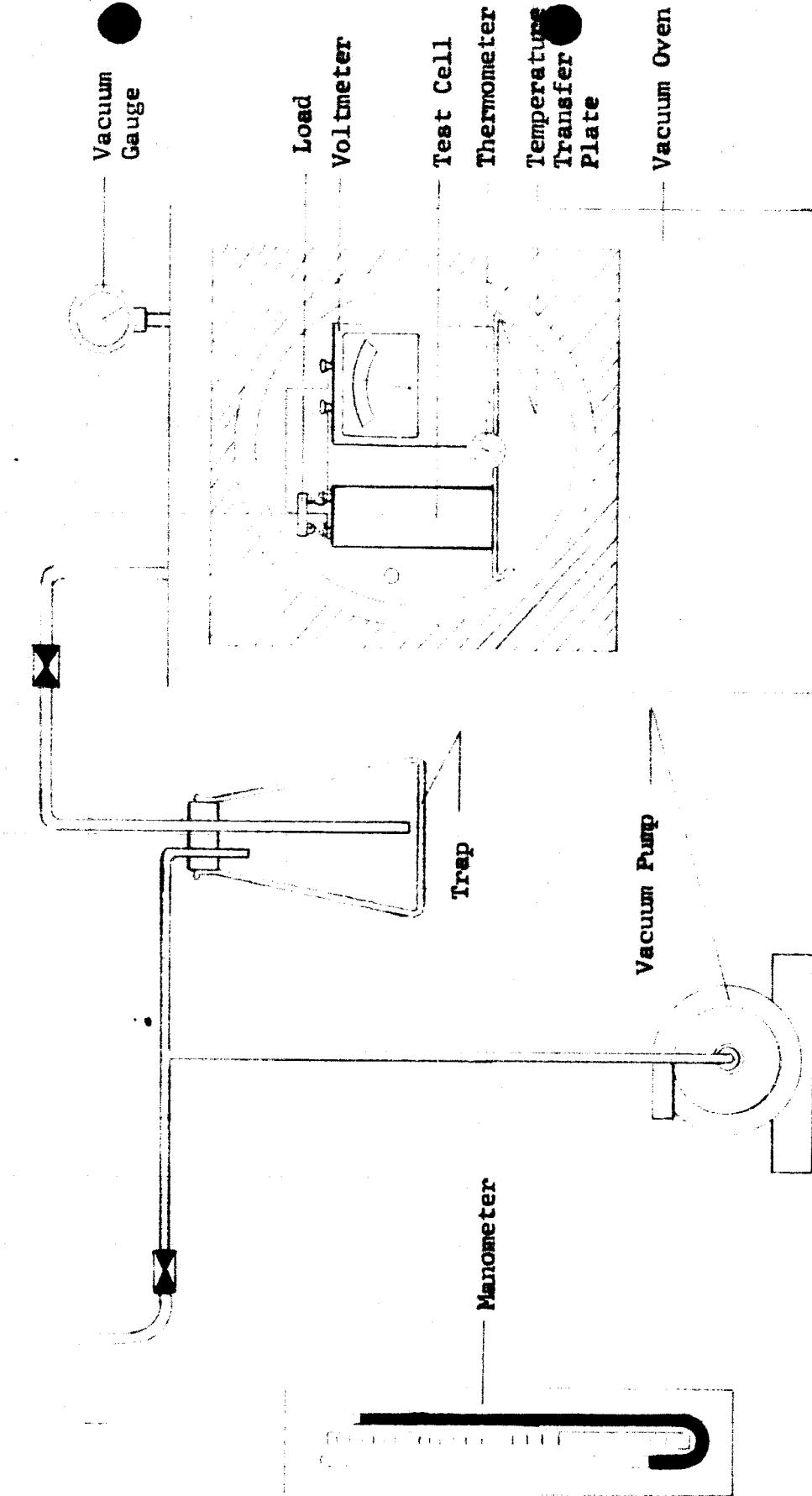


Discharged through constant
resistance of 23 ohms -
current calculated from
voltage.

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FIGURE 5

VACUUM DISCHARGE APPARATUS

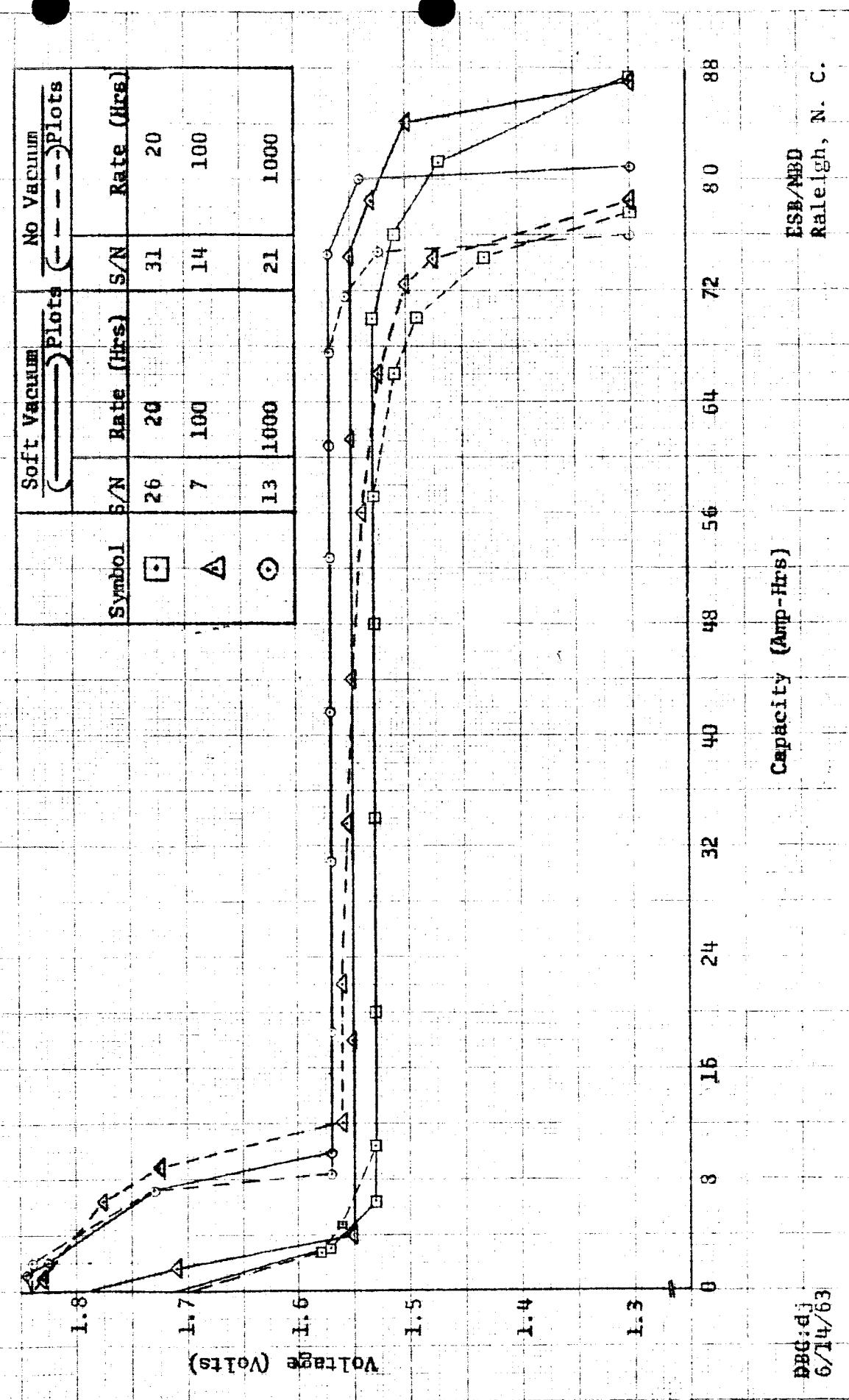


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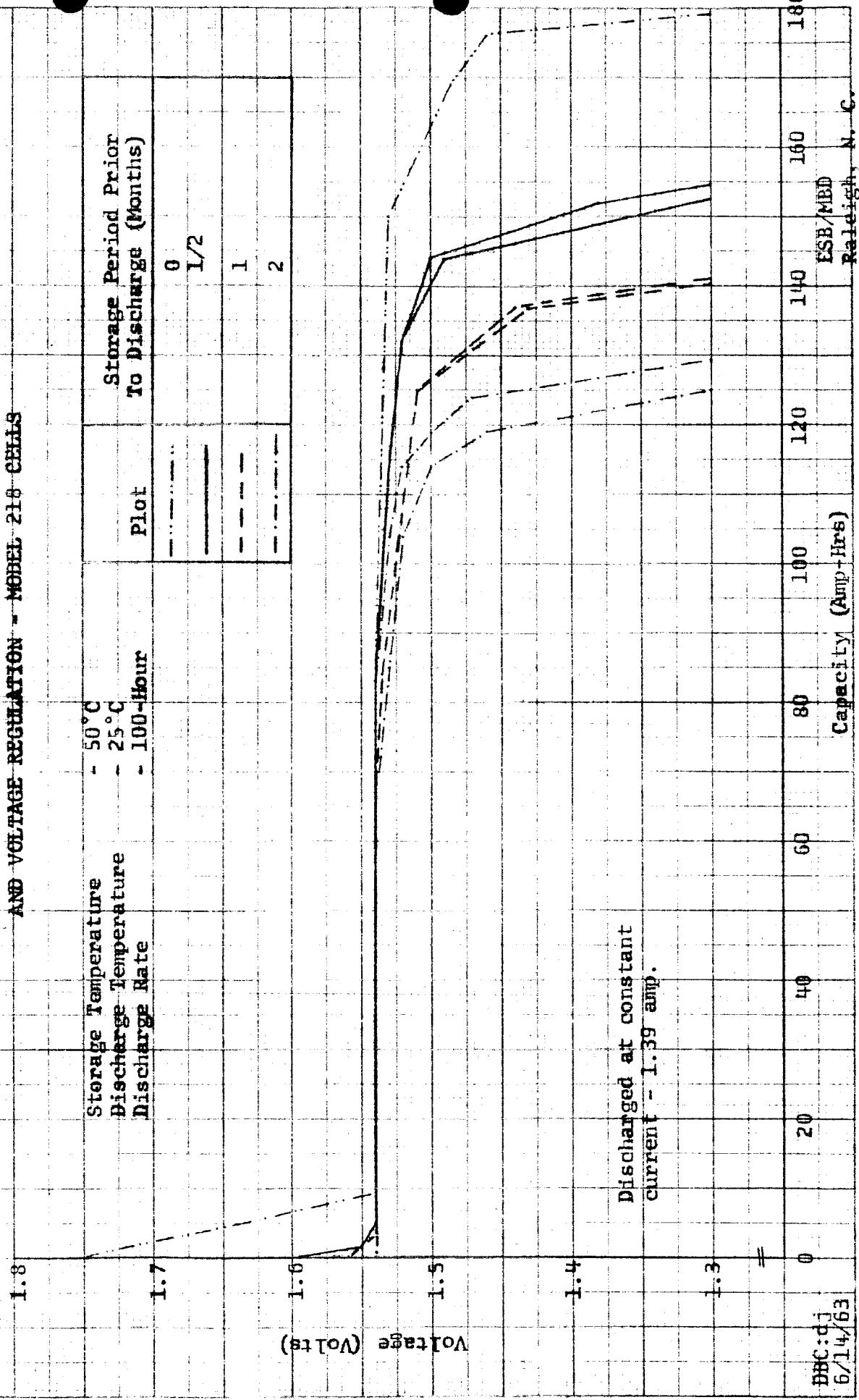
FIGURE 6
MODEL 217 DISCHARGES AT 50°C
VACUUM VS NON-VACUUM COMPARISON

Symbol	Soft Vacuum		No Vacuum	
	S/N	Rate (hrs)	S/N	Rate (hrs)
□	26	29	31	20
△	7	100	14	100
○	13	1000	21	1000



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FIGURE 7
**EFFECT OF CHARGED STAND ON DISCHARGE CAPACITY
AND VOLTAGE REGULATION - MOBEL 218 CELLS**

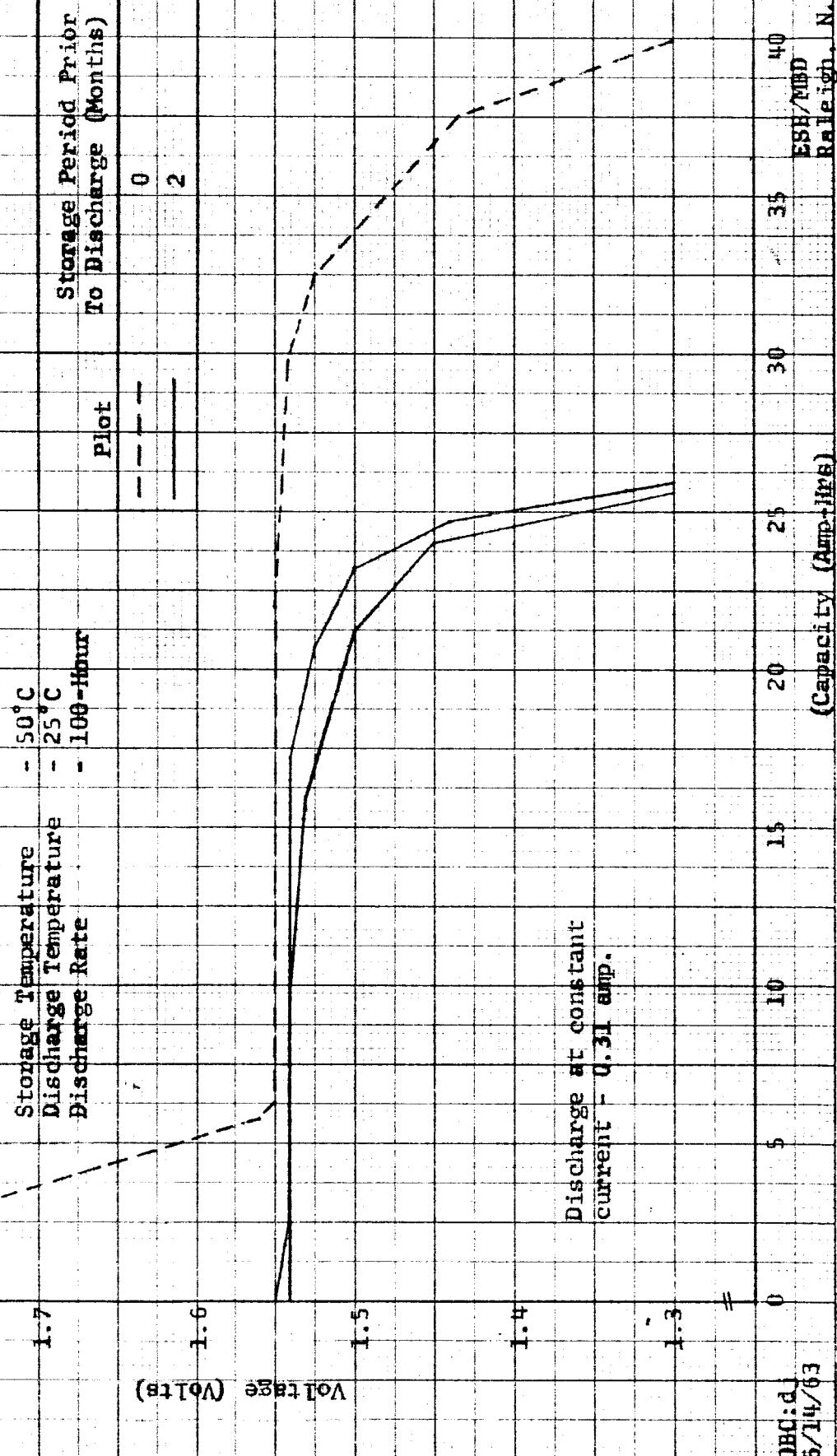


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FIGURE 8

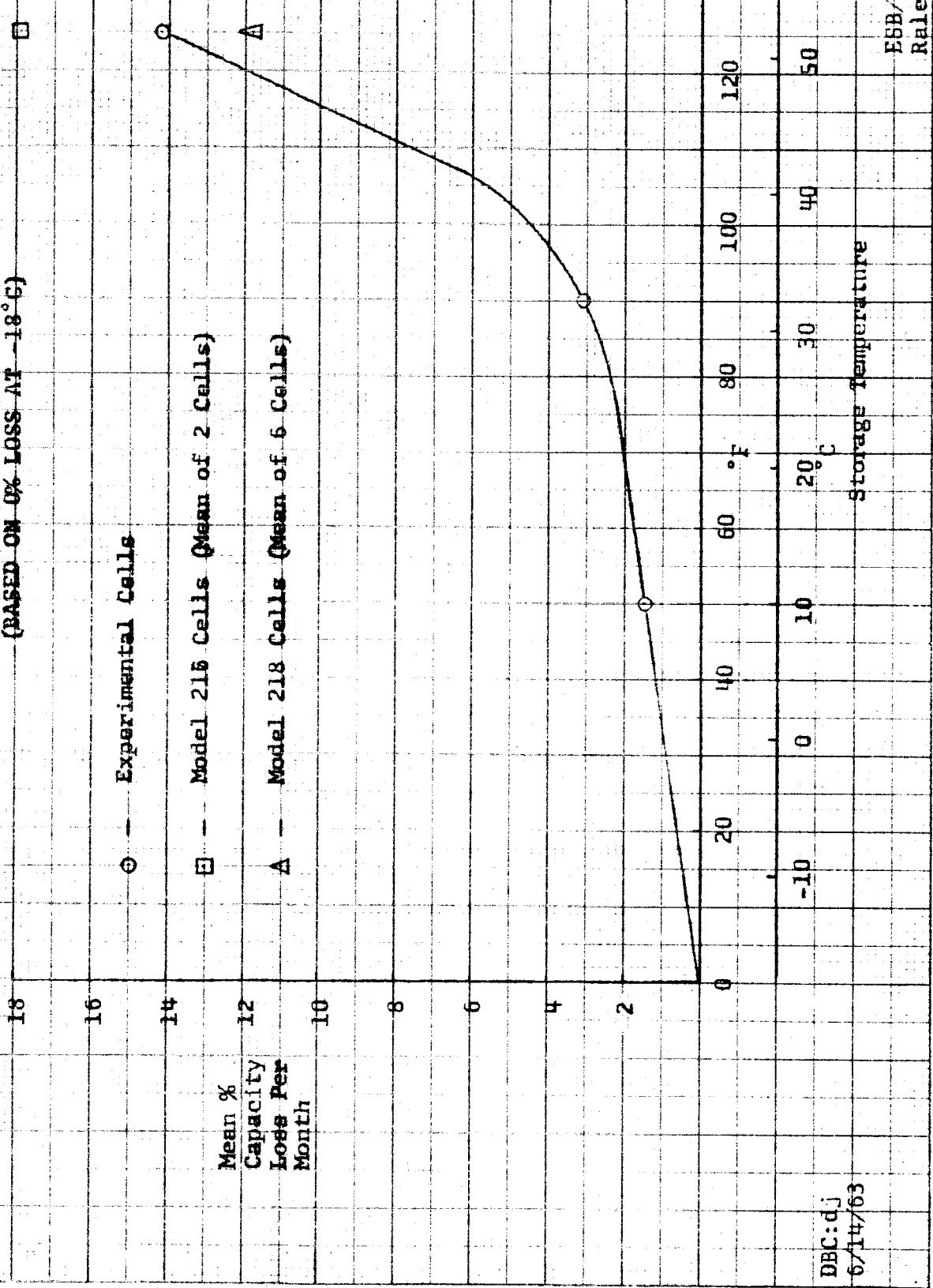
EFFECT OF CHARGED STAND ON DISCHARGE CAPACITY
AND VOLTAGE REGULATION - MODEL 216 CELLS



KODAK 10 X 10 TO THE 1/2 INCH
KODAK SAFETY FILM
KEUFFEL & SHERE CO.
NEW YORK

359-11

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FIGURE 9
CAPACITY LOSS VERSUS STORAGE TEMPERATURE
(BASED ON 0% LOSS AT -18°C)



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FIGURE 10

CHARGED CAPACITY RETENTION OF EXPERIMENTAL CELLS STORED AT 10, 32, & 52 °C
(BASED ON 100% RETENTION AT -18°C)

PLOTS OF OBSERVED RETENTION FOR FIRST 3/4 MONTH THEN MEAN
OF OBSERVED RATES THEREAFTER. LONGEST TIME POINTS PLOTTED FOR COMPARISON.

